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[redacted]

TECHNICAL MEMORANDUM

To: John C.

From: [redacted] STAT

Subject: Optical Image Manipulation Laboratory Support Program Outline of Experiments and Lectures

STAT Reference: [redacted]2201201-TM-70-1

Date: 25 April 1970

Enclosed with this memorandum is a program outline and schedule for the laboratory facility and image processing lecture series. Also included are notes covering the first lecture on the subject of the hologram interferometer, coherent processor and matched hologram detection filter.

The initial series of lectures will be closely related to the initiation of support activity for the image technology laboratory program. The lectures are directed to contribute to the set-up of the components, the implementation of the image processing operations and to provide a comprehensive understanding of the technology. Once initial direction has been gained in the support activity the lecture series will become concerned with more fundamental and broader concepts regarding image processing technology, including geometrical and physical optics, image formation, information theory, and aspects of different forms of information recording systems.

A general outline of the contents of the lecture series is attached to this cover letter. We should approach this schedule flexibly so that pertinent questions and problems can be thoroughly

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discussed as they arise during the course of this program. However the lectures should be conducted as described in technical memorandum [redacted]TM-70-1 dated 11 February 1970, with a minimum of two hours devoted to this portion of the effort at each bi-weekly visit. In this form, namely a classroom approach, we can cover the topics thoroughly and in an organized manner.

Also attached is a general outline of the laboratory programs to be conducted at the [redacted] These experiments are directed to utilize the two research optical benches and the interferometer system, and to activate operation that represents state-of-the-art capability in optical image processing. The experiments will include coherent, partially coherent and incoherent processes, utilizing laser and thermal sources. The experiments will be directed to the optimization of information extraction from imagery.

PSC/c
Enclosure

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STAT [redacted] Program Date April 27, 1970

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STAT Subject [redacted] Instructor's [redacted] STAT

STAT This notebook contains laboratory notes by

STAT [redacted] personnel working on the [redacted] STAT

[redacted] program. Reference is

made to the technical memorandum [redacted] 220101 STAT

TM 70-1 dated 25 April 1970 that outlines

the objectives of this program and the time

schedule. The first effort to be conducted

is directed to set-up the interferometer for

fabricating hologram detection filters (also

usable for other types of holograms, testing

and measuring optical surfaces, etc:) and

the T/O bench for coherent image processing

and for holographic target detection.

9:15 am to 9:45 Program initiated with a meeting

STAT in [redacted] office, attended by STAT

[redacted]

of effort and schedule.

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Tutorial Session's Topics

Objective

The objective of the tutorial sessions is to present a comprehensive analysis of image processing technology and related facets of image formation and information and communication theory. During the initial phase of this program, and at times when new systems are being initiated and activated, the tutorial subjects will be more closely directed to system's concepts and systems analysis. Otherwise a more general approach to the technology will be taken in presenting the subject matter.

An outline of the content to be covered is as follows :—

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Subject outline

1. Fourier transform hologram generation
   Hologram interferometer systems analysis
   Target Detection using Hologram matched filters
   Coherent Image Processor
   Systems Analysis

2. Concepts of Image Processing + Image Theory
   Fourier Series and Optical Transformation
   Linear System Definition
   Fourier Transform Examples
   Even + Odd Functions
   Shifting Theorem
   Differentiation and Integration
   Addition
   Convolution
   Correlation
   Complex Conjugates

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The Dirac Function
The Sampling Theorem
Aliasing
The Autocorrelation Function and Spectral Density

3. Optical Systems
Coherent Processing
Incoherent Processing
Optical System Configurations + Analysis
One, two + three lens processors
Interferometers
Film as a Processing System Component
Film linearity assumptions
Grain noise (the 'noise-modulated' image)
Matched in-line + holographic filters
Inverse filters (in-line + holographic)
Weiner filters

4. Communication Theory Systems Analysis

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Linear Systems

Eigenfunctions

Convolution

Examples

Modulation

AM, SSB, FM, FSK, ΦM

Sampling Theorem

Aliasing

Discrete Fourier Transform

FFT

Probability Theory

Discrete Probabilities

Random Variables

Probability Density Functions (PDF)

Random Processes

Autocorrelation Function

Power Spectrum

PDF of Samples

Linear Filtering

Match

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Weiner filters

Kalman filters

Detection theory

Likelihood Ratio

Maximum likelihood estimation

Data transmission

Measurement of Information

Entropy

Source encoding

Channel Capacity

Binary Symmetric Channel

Continuous, Bandlimited Channel

Redundant Coding

Algebraic Codes

Convolution Codes

5. Digital Image + Analog Image Processing

Combined Analysis

Optimized Combination

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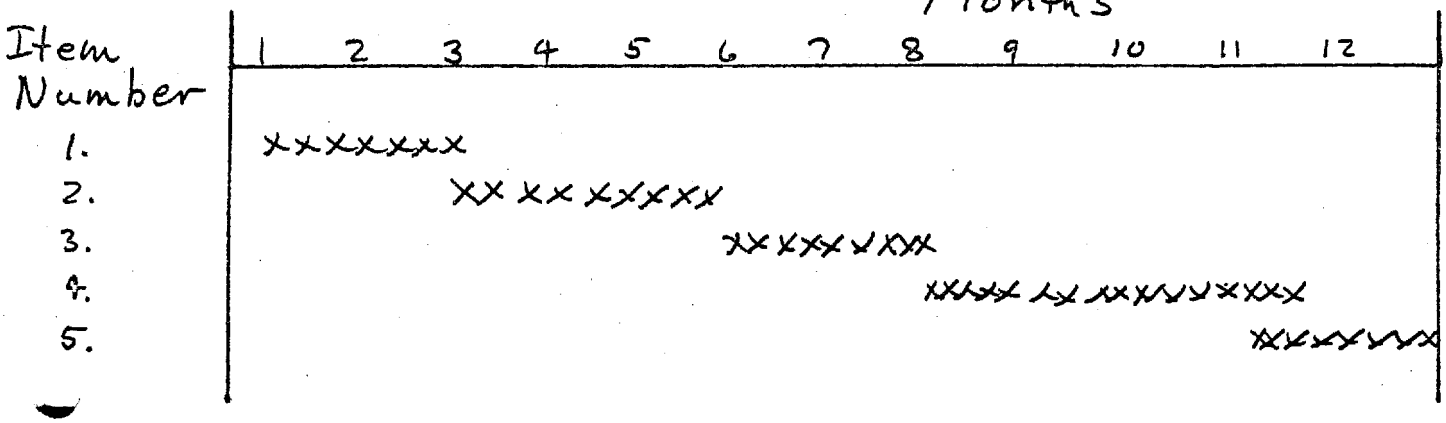
Schedule for Tutorials



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Laboratory Topics

Image Processing Technology

Subject areas

1. Holographic technology and target detection.
2. Image processing technology (image manipulation and image restoration).
3. Physical optics technology (analog optical mathematical operations and applications).

Program Schedule

Months

Subject areas	1	2	3	4	5	6	7	8	9	10	11	12
1.	xxxxxxxxxxxx											
2.	xxxxxxxxxxx

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Holographic Technology and Target Detection

Objective

The initial objective of this program area is to place the holographic interferometer and coherent optical bench into operation. These systems can be made operational within the first six to eight weeks of the program with utility demonstrated by eight to twelve weeks. The holographic interferometer will be set up for the generation of Fraunhofer holograms for matched filtering (detection filtering as the initial objective). The system will also have the capability for the generation of Fresnel holograms by removal of the Fourier transform lens. A slight modification will allow gen[illegible]

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holograms with a point reference source. Such holograms can be reconstructed with small point sources such as with a flashlight bulb. The interferometer can also be used for testing optical components and for hologram readout.

The coherent bench will be set-up for the target detection experiment, using imagery generated for the purpose and the filters generated on the interferometer. The coherent system can also be used for other coherent image processing applications and hologram reconstruction.

During this initial effort we will set these two systems up for the general utility described here, but more specifically for target

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detection, with filters and imagery available for demonstration. The systems will have flexibility for use as a tool for the special studies frequently conducted by the laboratory.

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Image Processing Technology

Objective

The primary emphasis of the laboratory effort will be directed to image processing activity on the Bech optical bench, using controlled coherence (generally partially coherent) and amplitude filters. The activity will be directed to implement and develop image manipulation and image restoration. The details of this effort are more thoroughly described in the program proposal, and will be covered in detail when this activity is initiated. This effort will be initiated during the third month of the program following implementation of the

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holographic interferometer and coherent processor.

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Physical Optics Technology

Objective

Analog operations with optical systems provide an efficient means to handle large amounts of information. There are many mathematical operations that can be performed, as is demonstrated by the list of topics to be covered by the tutorial sessions. Fourier transformation is perhaps the most familiar operation utilized in optical processing. Image coding and recording operations are readily available, as well as correlation procedures and power spectrum synthesis. Many of these operations will be used in the image processing activity although for

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purposes of completeness we will consider them individually. Knowledge and experimental expertise with these operations will provide more depth in developing analog applications to image processing and more flexibility in laboratory analysis of imagery.

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Laboratory Program #1

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1. Holographic Technology and Target Detection

Program Outline

1. Interferometer set-up
2. Fresnel hologram generation and reconstruction
3. Coherent processor set-up with off-axis readout capability (or on-axis with prism phase shift) preferably with TV monitor for readout.
4. Target generation with format of scene including a number of target types (autos, buildings, etc.) including the target to be detected.
5. Fraunhofer hologram generation for target detection.
6. Trouble shooting operations on the

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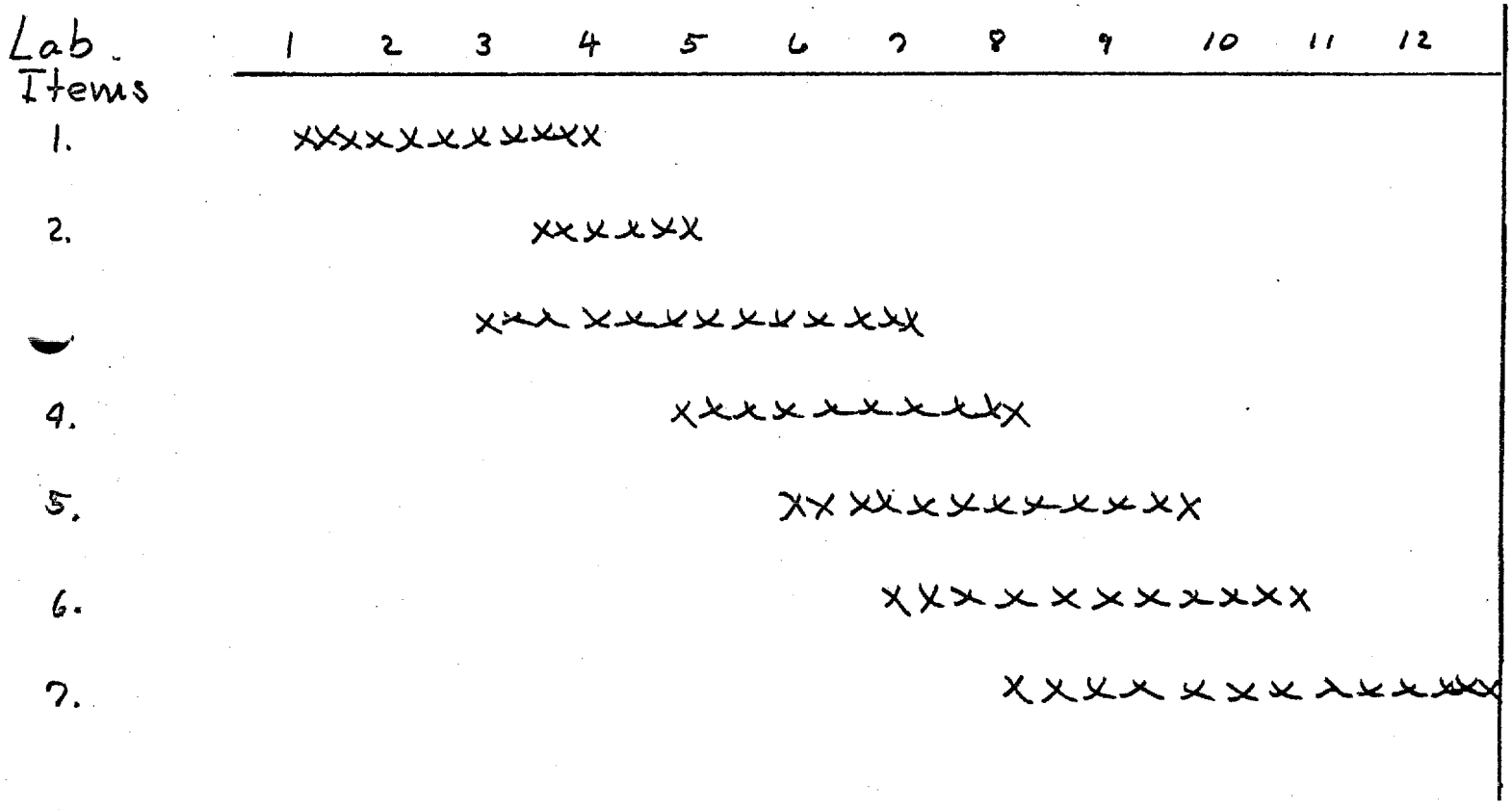
interferometer and coherent processor.

7. Target detection operations and demonstration.

Program Schedule



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Lecture Notes

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Holographic Filtering

Whenever a large collection of photographic film exists upon which is recorded various targets or signals one is faced with the problem of accurately and efficiently locating pertinent information. Detection filtering or target recognition methods are well known in the communication field and are successfully applied to the detection of signals recorded in a noisy medium. The matched filter is the more common solution to the electrical engineering detection problem. Its application to optical detection of imagery has been investigated using [redacted] and

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holographic techniques. There are several promising features to optical detection that can prove valuable to reconnaissance activities. This and the immediately following sessions will look into the application of holographic filters to target detection. It will be seen that the method can be successfully and accurately applied and that holographic filters can be readily generated when the interferometer is available, as it will be during these initial weeks after it is set up.

Let us first consider several basic points concerning target detection. The information

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recorded on a photographic image is formed by the imaging lens according to the equation

$$I_{im}(\underline{x}) = \int_{-\infty}^{\infty} I_{ob}(\underline{y})\, S(\underline{x}-\underline{y})\, d\underline{y}$$

which describes that the image intensity distribution is formed by the convolution of the object intensity distribution $I_{ob}(\underline{y})$ with the camera point spread function $S(\underline{x})$. The underline denotes vector space. In image restoration applications one is involved with operating on the point spread function term. In target detection one is involved with operating on the intensity distribution of a particular target or signal [redacted] Thus STAT

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initial discussion we will consider the coherent processor for operating on the photographic image and the interferometer for generation of the matched detection filter. First we must consider the Fourier transform operation and its inversion. We will assume for the moment that it can be performed by a coherent optical system. The fact that it can will be demonstrated later.

Inversion Theorem

The Fourier transform can be expressed as

$$F(\underline{\nu}) = \int_{-\infty}^{\infty} f(\underline{x}) e^{i \frac{2\pi \underline{\nu}\,\underline{x}}{\lambda F}} d\underline{x}$$

Consider

$$\int_{-\infty}^{\infty} F(\underline{\nu}) e^{-\frac{2\pi i \underline{\nu} \underline{x}'}{\lambda F}} d\underline{\nu}$$

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$$\int_{-\infty}^{\infty} F(\nu)\, e^{-\frac{2\pi i \nu x'}{\lambda F}}\, d\nu = \iint_{-\infty}^{\infty} f(x)\, e^{\frac{2\pi i \nu x}{\lambda F}}\, e^{-\frac{2\pi i \nu x'}{\lambda F}}\, dx\, d\nu$$

$$= \int_{-\infty}^{\infty} f(x) \left[\int_{-\infty}^{\infty} e^{\frac{2\pi i \nu}{\lambda F}(x-x')}\, d\nu \right] dx$$

Definition of Delta function

$$\delta(x-x') = \int_{-\infty}^{\infty} e^{\frac{2\pi i \nu}{\lambda F}(x-x')}\, d\nu$$

$$\int_{-\infty}^{\infty} F(\nu)\, e^{-\frac{2\pi i \nu x'}{\lambda F}}\, d\nu = \int_{-\infty}^{\infty} f(x)\, \delta(x-x')\, dx$$

$$f(x') = \int_{-\infty}^{\infty} F(\nu)\, e^{\frac{2\pi i \nu x'}{\lambda F}}\, d\nu$$

Ref. Papoulis, A. "The Fourier Integral" McGraw-Hill Book Co. NY 1962

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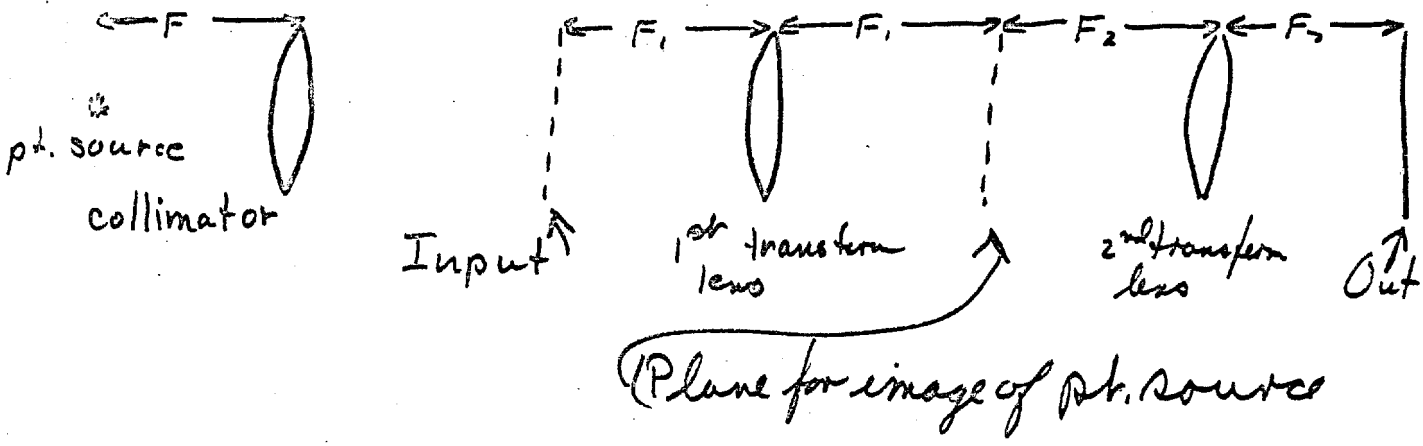
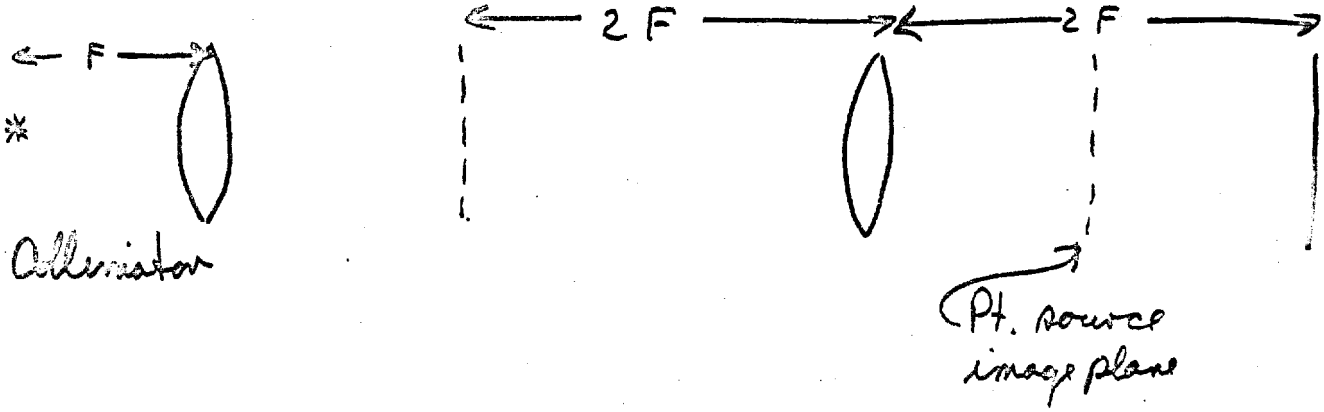
of the point spread function and describes the optical transfer function of the camera system. This can be performed with a number of different optical system configurations. Several of these are discussed here.

Three lens system



Two lens system



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Pt. source need

nsform plane

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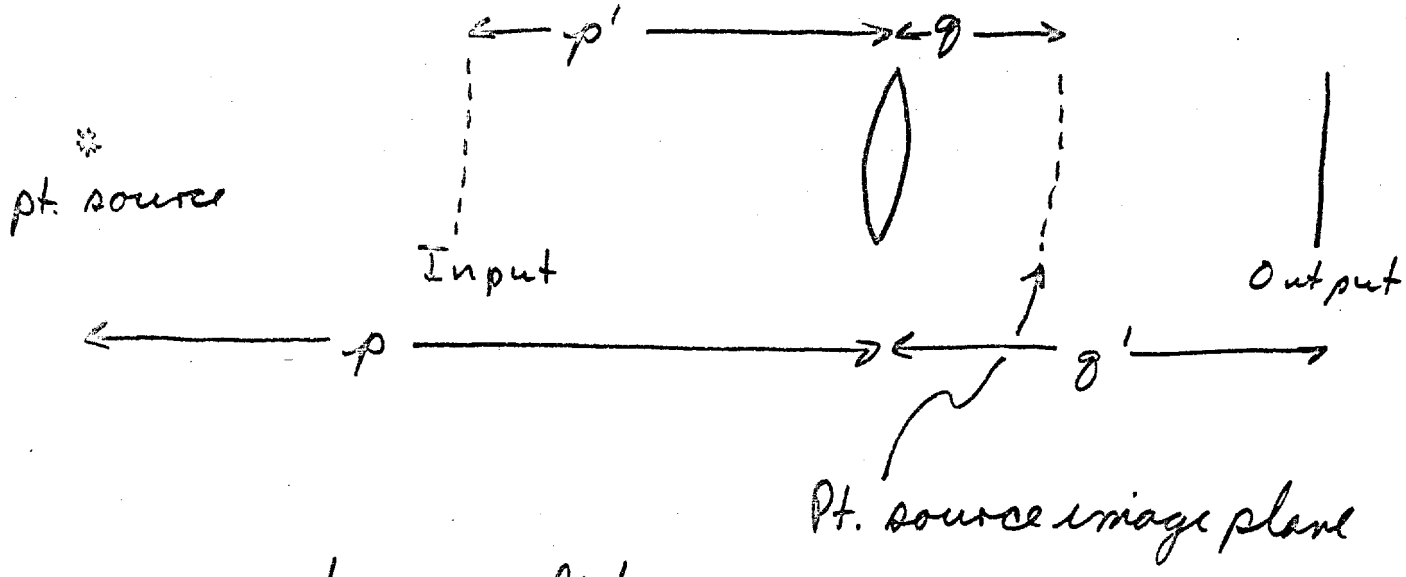
One lens system



Operating condition $\frac{1}{f} = \frac{1}{p} + \frac{1}{q} = \frac{1}{p'} + \frac{1}{q'}$

Gaussian imaging conditions hold for both the source and the input image to be processed.

Two lens system is most popular in image processing applications. It provides most flexibility, and only one processing lens so that highest image quality can be maintained. Trade-offs of each must be considered for optimum selection for any given application.

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The operations of Fourier transformation and inverse transformation are performed by coherent optical systems. As will be demonstrated the Fourier transformation of a coherently transilluminated image occurs at the image plane of the point source. If the image is expressed as

$$I_{im}(\underline{x}) = I_{ob}(\underline{x}) \circledast S(\underline{x})$$

where $\circledast$ denotes convolution, then in the Fourier transform plane we have

$$\tilde{I}_{im}(\underline{\nu}) = \tilde{I}_{ob}(\underline{\nu}) \cdot \tilde{S}(\underline{\nu})$$

where

$$\tilde{I}_{im}(\underline{\nu}) = \int_{-\infty}^{\infty} I_{im}(\underline{x})\, e^{\frac{2\pi i}{\lambda F}(\underline{\nu}\underline{x})}\, d\underline{x}$$

and where [illegible] transform

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If the detection filter $\tilde{F}(\underline{\nu})$ is placed into the transform plane then the output of the image processor is given by

$$I'_{im}(\underline{x}') = \left[I_{ob}(\underline{x}') \circledast S(\underline{x}')\right] \circledast F(\underline{x}')$$

The form of the output at the image plane is a correlation equation given by

$$I'_{im}(\underline{x}') = \int_{-\infty}^{\infty} \tilde{I}_{im}(\underline{\nu})\, \tilde{F}(\underline{\nu})\, e^{-\frac{2\pi i}{\lambda F}(\underline{\nu}\,\underline{x}')}\, d\underline{\nu}$$

$$= \int_{-\infty}^{\infty} I_{im}(\underline{x})\, F(\underline{x}+\underline{x}')\, dx$$

The visual output will demonstrate a high degree of correlation between any target matched to the filter. This degree of correlation will be represented by peaks of intensity in the output plane at target format positions.

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The intensity peaks are a measure of the degree of correlation and threshold values can be derived to provide outputs within given confidence levels.

Interferometer

There are many designs that can be applied to the interferometer set-up. But basic to each is the Fourier transform hologram capability. Let us consider the Mach Zehnder design first used for holograms by A. VanderLugt. (Some other designs are included in the reference below). The input function (the target for which a filter is desired)

Ref. VanderLugt, A. Practical Considerations for the Use of Spatial Carrier-Frequency Filters, Applied Optics 5, 1760 (1966)

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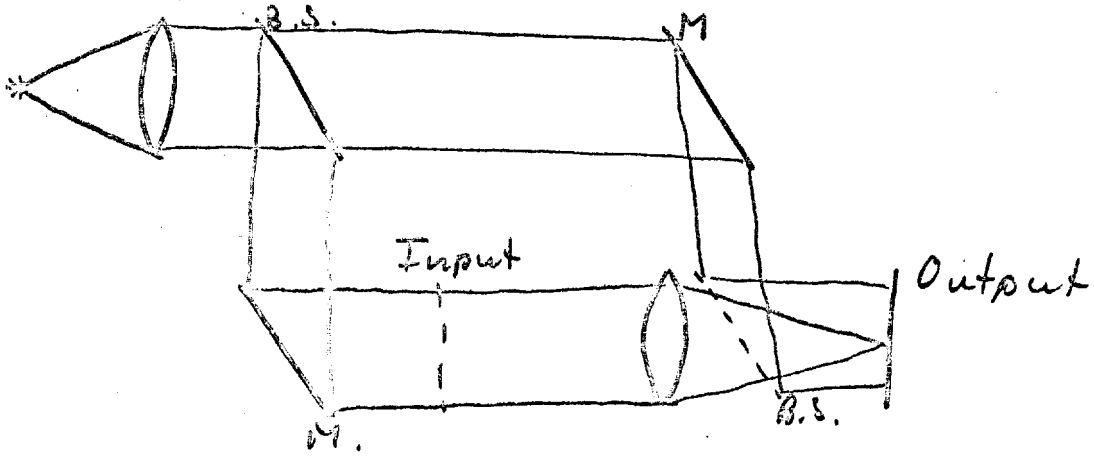
Modified Mach-Zehnder Interferometer



is placed at I and the Fourier transform is recorded at the output provided that the sum of the transform with the reference beam is a positive function. That is

$$\tilde{F}(\underline{\nu}) = \left\{ \left[K e^{i\alpha(\underline{\nu})} + \tilde{I}_1(\underline{\nu}) \right]^{\pm 2} \right\}^{-\gamma/2}$$

where the term in the brackets must be positive. $\tilde{I}_1(\nu)$ is the transform of the input function, $I_1(x)$, for which the detection filter is desired. The squaring operation is performed by the intensity recording by the film of an amplitude function. Film processing is defined by a

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$\tilde{F}(\underline{\nu})$ is the amplitude transmittance, therefore the ½ power. In detail we have

$$\tilde{F}(\underline{\nu}) = \left\{ K^2 + \left|\tilde{I}_1(\nu)\right|^2 + Ke^{-i\pi(\nu)}\tilde{I}_1(\nu) + Ke^{i\pi(\nu)}\tilde{I}_1^*(\nu) \right\}^{-\gamma/2}$$

When the film is processed to $\gamma = -2$ we get the term inside the brackets. The first two components are undiffracted elements whereas the last two have linear phase shifts that cause the holographic off-axis output. Note that the third term is diffracted opposite to the fourth. If we consider the fourth term we note the matched filter component desired for this first experiment.

Although many limiting arguments can be brought out as to possible limiting factors in recording functions (especially Fourier transform functions)

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on film it will be seen that the method can work with significant results. In affect it should be emphasized that the "engineering approach" to the use of film yields satisfactory results. The exact description of the record however can only be developed within certain linear regions.

During the next few weeks we will consider the system components in more detail to define operational limits and expected behavior. Several interferometer configurations are attached here for discussion and to aid in determining design possibilities for the lab program.

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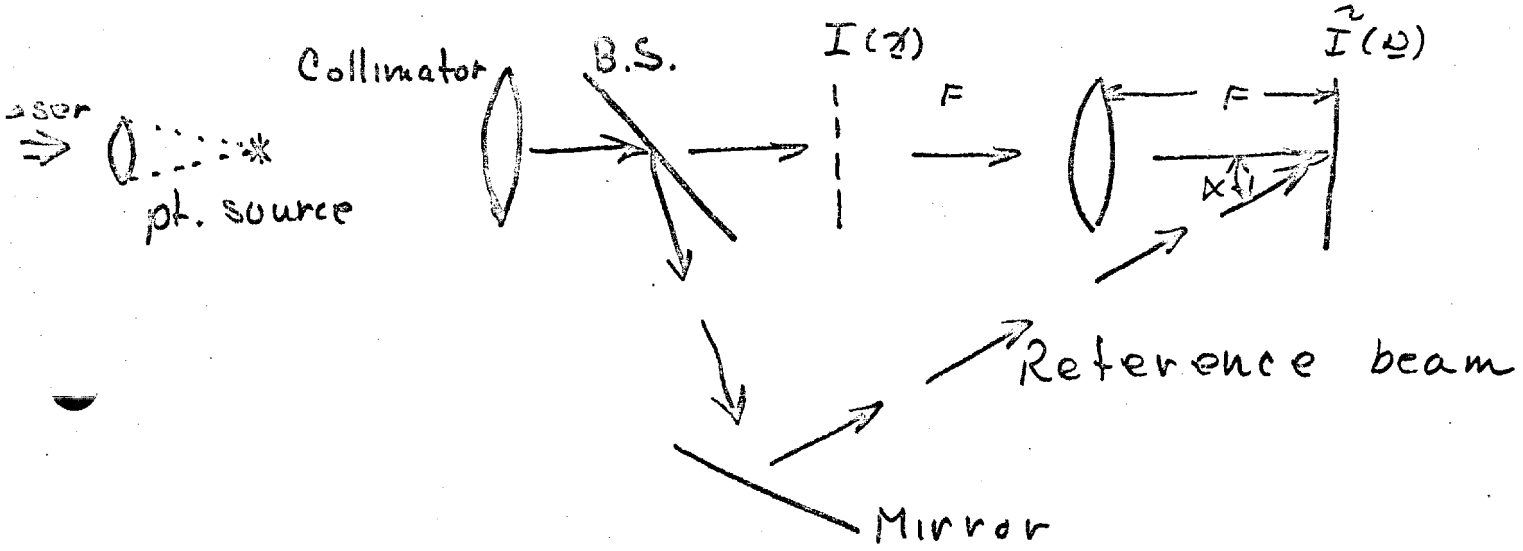
Some Different Interferometer Configurations



This one mirror, one beam splitter configuration is good except for the large angle required for reference wave input.

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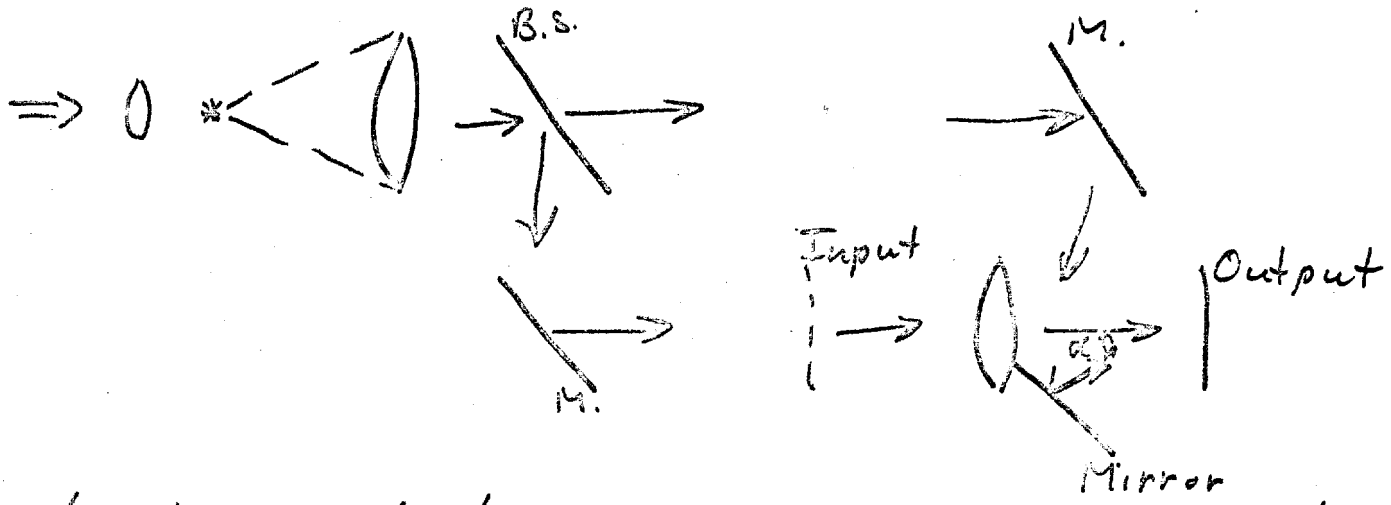

This form of the Mach Zehnder interferometer avoids spherical aberration problems when a beam splitter is placed after the transform lens. Also angle α can be minimized compared to the one BS, one M configuration.

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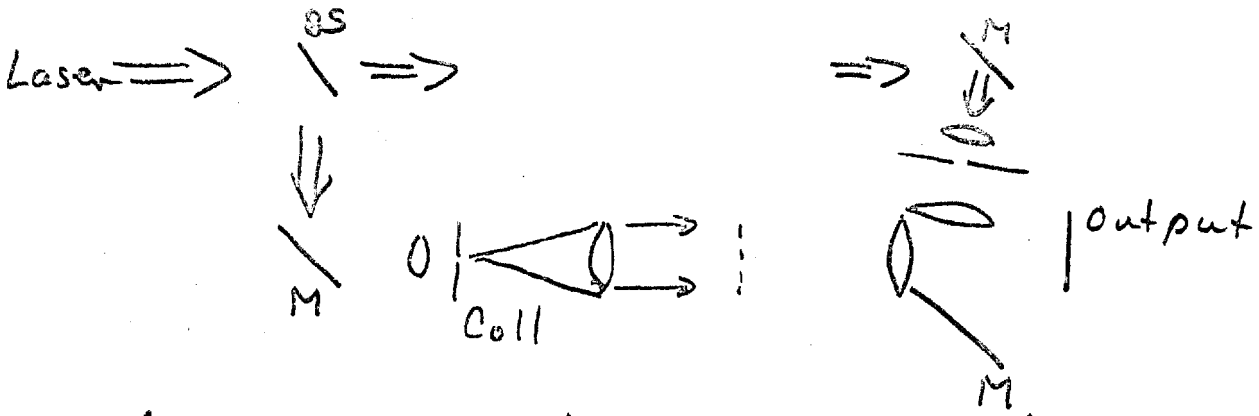

- This modified form allows the use of small components up to the final operation. However it requires two collimators if a plane reference wave is desired. Such a reference wave is not always necessary. Other configurations can be developed.

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